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GREGOR: the New German Solar Telescope

H. Balthasar[1], O. von der Lühe[2], F. Kneer[3], J. Staude[1], R. Volkmer[2], T. Berkefeld[2], P. Caligari[2], M. Collados[5], C. Halbgewachs[2], F. Heidecke[2], A. Hofmann[1], M. Klvaňa[4], H. Nicklas[3], E. Popow[1], K. Puschmann[3], W. Schmidt[2], M. Sobotka[4], D. Soltau[2], K. Strassmeier[1] and A. Wittmann[3]

[1] *Astrophysikalisches Institut Potsdam, Germany,*
[2] *Kiepenheuer-Institut für Sonnenphysik, Freiburg, Germany,*
[3] *Institut für Astrophysik, Universität Göttingen, Germany,*
[4] *Astronomical Institute AS, Ondřejov, Czech Republic,*
[5] *Instituto de Astrofísica de Canarias, La Laguna, Spain*

Abstract. GREGOR is a new open solar telescope with an aperture of 1.5 m. It replaces the former 45-cm Gregory Coudé telescope on the Canary island Tenerife. The optical concept is that of a double Gregory system. The main and the elliptical mirrors are made from a silicon-carbide material with high thermal conductivity. This is important to keep the mirrors on the ambient temperature avoiding local turbulence. GREGOR will be equipped with an adaptive optics system. The new telescope will be ready for operation in 2008. Post-focus instruments in the first stage will be a spectrograph for polarimetry in the near infrared and a 2-dimensional spectrometer based on Fabry-Pérot interferometers for the visible.

1. Introduction

Magnetic features on the sun are rather small or have an internal fine structure with typical scales of the order of 50 − 100 km. Variations occur on short time scales of a few minutes. To collect the required number of photons, large telescopes are needed to investigate such features. Such a telescope must have good polarimetric properties in order to enable high precision polarimetric measurements. A German consortium consisting of the Kiepenheuer-Institut für Sonnenphysik, the Institut für Astrophysik in Göttingen and the Astrophysikalisches Institut Potsdam presently builds a new solar telescope with an aperture of 1.5 m, GREGOR. International partners in the construction are the Astronomical Institute Ondřejov (Czech Republic) and the Instituto de Astrofísica de Canarias (Tenerife, Spain). GREGOR replaces the previous 45-cm Gregory-Coudé-telescope on Tenerife. Reports on the progress in constructing this telescope can be found in Volkmer et al. (2005), Volkmer et al. (2006) and Volkmer (2007).

GREGOR is designed as an open telescope, so the air can flow freely through the telescope. Problems with plane-parallel entrance windows of the required size are avoided this way, but now one has to care for the absorbed heat at the surfaces which are exposed to the full sunlight. Roughly 2000 W of radiation fall

on a primary mirror of 1.5 m diameter, and with a coating of aluminum about 10% will be absorbed. Therefore, active cooling of the primary mirror is required to keep it at the ambient temperature. If the material of the mirror body has a high thermal conductivity, it is sufficient to blow cold air onto the backside of the mirror. This is the reason why we decided not to use a standard glass-ceramic. Instead, the main mirror and the two following ones will be made from a silicon-carbide material. Besides its high thermal conductivity, this material has also the advantage of a quite high stiffness, so that the mirror is less bent due to the changing orientation during the day. In addition, the mirror mount is designed to minimize the influence of gravitational forces on the mirror. On the other hand it is very difficult to produce a mirror of this size fulfilling the optical requirements. More details can be found in Krödel et al. (2006).

The telescope has an alt-azimuthal mounting, thus the telescope structure is very compact and mechanical problems are reduced to a minimum. To realize the concept of an open telescope, and in order to make room for the 1.5 m telescope, the dome of the GCT had to be removed. It was replaced by a foldable tent of the same type as that of the Dutch Open Telescope on La Palma. Since the erection of this new dome several strong storms passed Tenerife which the dome resisted. The telescope structure was mounted at the site in 2004 and is shown in Fig. 1. The movements of the telescope are computer-controlled guaranteeing a precise basic guiding. The fine tracking is done by an adaptive optics system.

The telescope is designed for the wavelength range 380 nm through 12 μm.

The operation of the telescope and the control of the post-focus instruments will be done from a separate room in the third floor of the building. Graphical interfaces give access to all instruments and sensors.

2. The Optical Path

A scheme of the optical path is displayed in Fig. 2. The optical concept is that of a double-Gregory Coudé telescope. This telescope has an effective focal length of 55 m. The first three mirrors are aligned along the same optical axis to keep instrumental polarization to a minimum until the secondary focus.

The primary mirror M1 has a diameter of 1.5 m, is shaped parabolically, and has a focal width of 2.5 m. Cold air will be blown into pockets on the back side of the body of the mirror to keep temperature differences to the ambient below 0.3 K, sufficient to avoid heat-driven air turbulence at the front surface of the mirror. The temperature of the cooling air is adjusted according to the prevailing air temperature.

At the primary focus F1 there is a field stop which allows a circular field of 150 arcsec diameter to pass, alternatively a wider hole with 300 arcsec width can be inserted. The rest of the light (more than 97%!) is deflected out of the telescope. Because of the concentrated light at this location, this field stop needs active cooling by a water circulation, which is realized in two circuits. This way, the temperature difference to the surrounding air will be kept below 5 K.

The secondary mirror M2 is an elliptical one with a diameter of 42 cm. The two focal lengths are 67 cm and 2.3 m. This mirror will absorb 6 W, therefore passive cooling is enough to avoid temperature differences of more than 2 K. The alignment of this mirror with respect to M1 is extremely crucial for the optical

Figure 1. The mechanical structure of the telescope on top of the building. The dome is folded down. The Vacuum Tower Telescope is seen in the background.

performance of the telescope. M2 will be mounted on a hexapod permitting the needed degrees of freedom for movements. These movements will be done under control of the adaptive optics system (AO).

Little space is available near the secondary focus F2, nevertheless there is the possibility to introduce a linear polarizer (a Marple-Hess prism) and one of two achromatic quarter-waveplates (380 – 800 nm and 750 – 1600 nm, respectively). All these elements can be rotated with a step width of 0.1 degrees allowing the instrumental calibration of the instrument and a proper measurement of the circular polarization. For alignments, also a grid target or a pinhole can be inserted here. A more detailed report on polarimetry with GREGOR is given by Hofmann (2006).

The tertiary mirror M3 is used to focus the telescope. It is again an elliptical mirror with a diameter of 36 cm. The focal lengths of this mirror are 1.6 m and 10.1 m. Passive cooling is sufficient for this mirror too.

M3 reflects the light beam to flat mirror M4 which is located at the intersection of the optical axis of the telescope and the elevation axis. M4 reflects the light into the elevation axis. From there the beam passes three more flat mirrors (M5 – M7), and is finally reflected into the azimuth axis of the telescope. Heat absorption is not a problem for these mirrors, so they are made from ZERODUR. For the case that turbulence occurs in this part of the optical

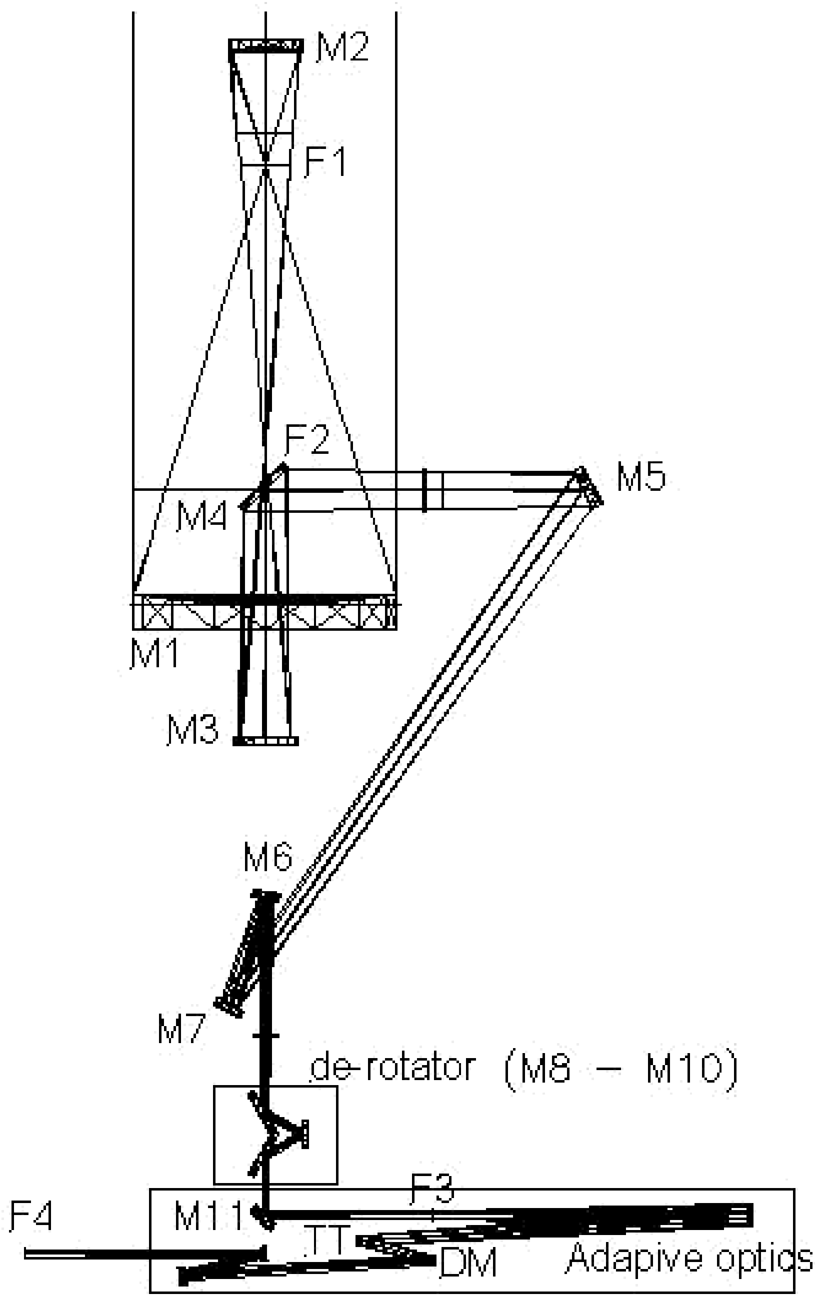

Figure 2. Optical scheme of the telescope.

path, glass plates are introduced between M4 and M5 and after M7, and the tube inbetween can be evacuated. For observations at wavelengths longer than 2.5 μm, these plates must be removed.

A disadvantage of the alt-azimuthal mounting is the rotation of the final image. This will be compensated by a de-rotator consisting of three flat mirrors M8 – M10. In addition, the de-rotator can be used to change the orientation of the image with respect to the post-focus instruments, e. g. the spectrograph slit. The de-rotator can be removed from the optical beam.

Mirror M11 reflects the light into the AO system. A filter wheel is placed at the tertiary focus F3; different field stops, a pinhole, a target, and a cover for dark exposures can be inserted here. Then the light passes the collimator M12, the tip-tilt mirror TT, the deformable mirror DM and the camera mirror M15, before mirror M16 sends the light to the requested post-focus instrument. M11 and M16 can be removed to bypass the AO. The deformable mirror DM has 80 electrodes and a free aperture of 55 mm. Each post-focus instrument will have its own wavefront sensor of Shack-Hartmann type. The wavefront sensors will have 78 usable sub-apertures. One sub-aperture will be covered by 24 × 24 pixel, and one pixel will correspond to 0.5 arcsec. Further details about the AO-system can be found in Soltau et al. (2006).

3. Post-focus Instruments

In the first stage GREGOR will be equipped with a 2D-spectrometer and a slit spectrograph together with an infrared polarimeter. Most post-focus instruments are placed in the optical laboratory in the fifth floor of the building, just below the telescope. The entrance slit and the polarimetry unit of the spectrograph are placed here too, then the light is reflected down to the fourth floor where stable conditions are guaranteed for the spectrograph.

The 2D-spectrometer is an upgrade of the Göttingen Fabry-Pérot spectrometer which was operated successfully for many years at the Vacuum Tower Telescope (VTT). It is based on two new tunable Fabry-Pérot interferometers (FPI) which have a diameter of 70 mm. The FPIs are placed in the collimated beam near the telescope pupil. The usable wavelength range is 530 – 870 nm, and the resolving power is of the order of 250000.

The slit spectrograph of Czerny-Turner type is optimized for the near infrared to be used with the Tenerife Infrared Polarimeter (TIP 2, Collados et al. 2007), which was operated at the VTT before. The heart of the spectrograph is the grating previously used at the GCT. The focal lengths of both, collimator and camera mirrors of the new spectrograph are 6 m. At 1.1 μm it has a resolving power of 525000, and the dispersion corresponds to 52 pm/mm. The spectrograph can be used for any single wavelength range in the visible too, only the dispersion is not well adapted to the pixel size of modern CCD-detectors. A few combinations of two visible ranges to be observed simultaneously are possible. A detailed description of the spectrograph is given by Collados et al. (2006).

Our plans also foresee to move the Polarimetric Littrow Spectrograph (POLIS) from the VTT to GREGOR as soon as GREGOR is ready. A description of this instrument was published by Beck et al. (2005).

One free optical table is available for experimental setups or guest experiments.

On a longer time scale, GREGOR will also be used for stellar astronomy, the Astrophysical Institute Potsdam plans a special spectrograph to obtain stellar

spectra over the whole visible range. This spectrograph will be placed in the fourth floor.

4. Conclusion

With its aperture of 1.5 m and equipped with an adaptive optics system, GREGOR will be the most powerful solar telescope for high resolution spectroscopy in the range from 380 nm through 2200 nm for the near future. GREGOR has good polarimetric properties and will be equipped with a polarimeter for the infrared and the visible spectral range (TIP and POLIS).

First light and commissioning are expected to occur in 2008.

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